

# FIELD EMISSION CHARACTERISTICS OF DIAMOND EDGE SHAPED EMITTERS FABRICATED USING NITROGEN-METHANE PLASMA

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## Abstract

A diamond based field emission device with low turn-on field and ability to produce high emission current is attractive for vacuum microelectronic applications. Recent research has suggested that nitrogen incorporated nano-crystalline diamond is advantageous for fabricating field emission devices as it is electrically conductive and exhibits low turn-on field [1]. Concurrently, an edge-shaped geometry could be better for high emission current since each edge can have multiple emission sites along the edge [2]. Thus, the utilization of edge-shaped geometry in nitrogen incorporated diamond promises an excellent field emission device. In this paper we report fabrication and field emission behavior of micro-patterned edge-shaped diamond field emission diodes fabricated using nitrogen-methane plasma.

The edge-emitter molds were fabricated from a silicon substrate utilizing silicon micropatterning and etching techniques. Further sharpening of the molds was performed by thermal oxidation of the silicon mold before diamond deposition. This oxidation process not only sharpened the edge but also served as a gate dielectric formation step for the triode device with built-in gate. Diamond was deposited into the edge molds by microwave plasma chemical vapor deposition (MPCVD) process using nitrogen-methane plasma. The deposited diamond film was characterized with energy dispersion spectroscopy (EDS), Raman spectroscopy, and scanning electron microscopy (SEM). Each diamond cathode array, consisted of 1000 edges with each edge base 15 $\mu\text{m}$  in width and 120 $\mu\text{m}$  in length, fabricated on a 1 $\text{cm}^2$  silicon chip and bonded to molybdenum substrate by a high temperature brazing process. The cathodes were tested for emission behavior in a diode configuration. Highly doped low resistivity silicon was used as the anode and a mica spacer was used to separate the anode and cathode. The diode was considered “turned-on” when a forward emission current of 1 $\mu\text{A}$  was obtained.

Fig. 1(a)-(b) compares the diamond edge geometry obtained from nitrogen-methane and hydrogen-methane plasma growth processes, while holding other fabrication parameters the same. Nano-crystalline diamond with an average grain size of 5-10nm as compared to 50-100nm was obtained from nitrogen-methane plasma growth and methane-hydrogen plasma, respectively. The smaller diamond grain size obtained from nitrogen-methane plasma growth has led to a sharper edge emitter and hence a higher field enhancement factor and lower turn-on field. Nitrogen incorporation in the as grown diamond film, as seen in EDS spectrum in Fig. 1(c) and Raman spectrum in Fig. 1(d), promotes  $\text{sp}^2$  bonding which increases the bulk conductivity of the diamond film and also improves the transport of electrons to the diamond-vacuum interface. Edge emitter diode fabricated from nitrogen-methane plasma displayed a low turn-on field of 2V/ $\mu\text{m}$  as compared to 5V/ $\mu\text{m}$  displayed by those fabricated using hydrogen-methane plasma compared in Fig. 2(a) [3]. The low turn-on cathode also displayed a high emission current of 5.3mA at 8V/ $\mu\text{m}$  as observed from Fig. 2(b). Lowering of turn-on field is attributed to the combination of higher bulk conductivity of deposited diamond and the ability to fabricate sharper edge emitter geometry as compared to that obtained from methane-hydrogen plasma.

In conclusion, diamond edge emitters were fabricated and their emission characteristics studied. Lowering of turn-on field was achieved by fabricating the edge emitters using nitrogen-methane plasma and emission current density of 5.3mA/ $\text{cm}^2$  was demonstrated. We have also fabricated a self-aligned gated diamond edge triode from a silicon-on-insulator (SOI) substrate using similar fabrication techniques. Details of the field emission triode behavior will be presented in the paper.

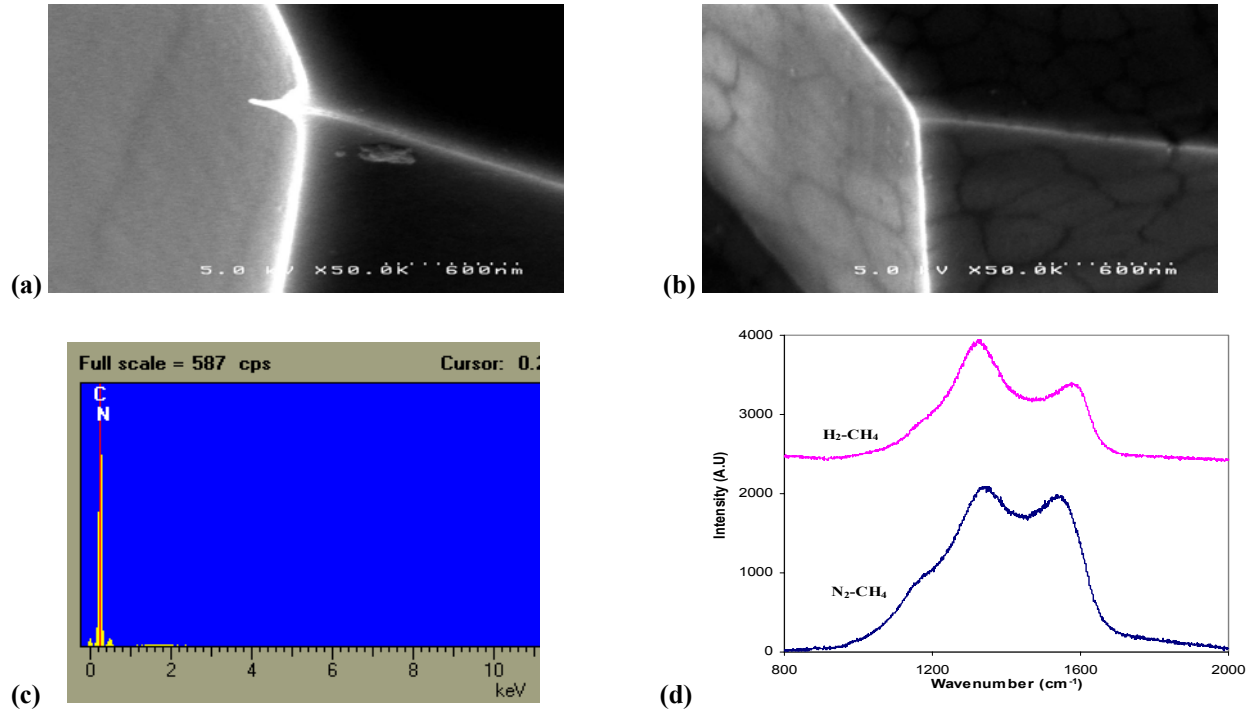


Figure 1. (a) High magnification SEM of edge emitter fabricated using nitrogen-methane plasma. (b) High magnification SEM of edge emitter fabricated using hydrogen-methane plasma. (c) Energy Dispersion Spectrum of diamond grown using nitrogen-methane plasma. (d) Comparison of Raman spectra of deposited diamond.

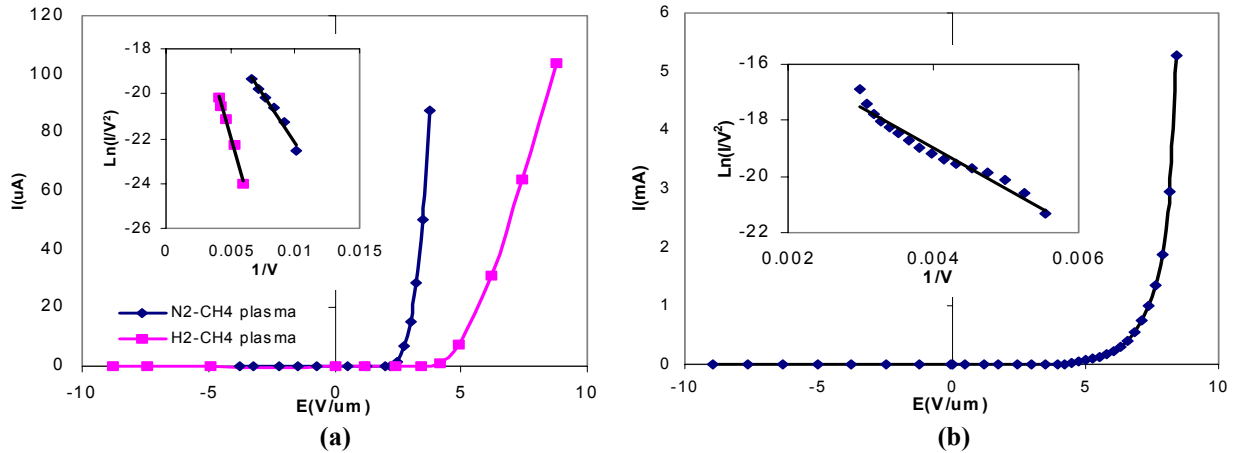


Figure 2. (a) I-E plot comparing field emission characteristics of edge-emitters fabricated using nitrogen-methane plasma and hydrogen-methane plasma. (b) High emission current characteristics of edge-emitters fabricated using nitrogen-methane plasma.

## REFERENCES

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